REVIEW
ARTICLE

Imaging in Tsunami Trauma

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In this article, the authors discuss and illustrate common imaging findings of patients who suffered from tsunami trauma. These include fractures, dislocations, aspiration pneumonia, soft tissue foreign bodies, tsunami sinusitis and other less frequent injuries.

KEY WORDS — radiological imaging, trauma imaging, tsunami

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Introduction

Natural disaster remains a significant cause of morbidity, mortality, loss of infrastructure and economical instability, especially in developing nations where aid and resources are limited [1,2]. Excluding disease epidemics or famines, a tsunami is among the top deadliest natural disasters on Earth with the Indian Ocean tsunami on 26 December 2004 being one of the most deadly in the recorded history. More than 200,000 people were killed or declared missing and more than a million people were displaced due to the event [1]. Tsunamis are not uncommon. The search of the National Oceanic and Atmospheric Administration (NOAA) database revealed 36 tsunamis occurred within 2 years following the Indian Ocean tsunami (from January 2005 to September 2008). Of these, six events (16.7%) resulted in either deaths, injuries or both. The medical effects of tsunami range from none (no death or injury), mild to severe (with deaths and/or injuries), depending on the magnitude of the tsunami waves and their location. The pattern of injuries and deaths related to tsunamis are different from other natural disasters. Tsunamis typically result in a high ratio of deaths per injuries because most victims do not survive long enough to reach medical care [3–5]. This is in contrast with earthquakes, where ones would expect by a rule of thumb of three injuries per every death [4]. Health effects of tsunamis, although mostly acute, can be delayed and prolonged. Survivors may present to healthcare facilities weeks or months after the tsunami incident due to various illnesses [4,6].

As tsunami occurrences are not infrequent, it is important for healthcare personnel in the areas at risk to prepare for and respond to the event promptly [7]. Adequate medical knowledge of

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how tsunamis impact on patients is a very important aspect for physicians in providing optimal medical and surgical management. Since the 26 December 2004 Indian Ocean tsunami, there have been several published data in medical literature describing trauma and illnesses related to the tsunami. To date, more than 600 articles have been published and are searchable via PubMed. The majority of these articles are related to psychosocial and clinical aspects of tsunami trauma. However, data regarding a role of diagnostic imaging in tsunami trauma are very limited [8].

In this article, we describe a pattern of injuries due to the tsunami. Imaging findings in tsunami patients are illustrated. Traumatic conditions, non-traumatic conditions, and the role of radiological imaging are discussed.

Dynamics of Tsunami and Pattern of Injuries

A tsunami is generated when a massive amount of seawater is displaced, usually due to an underwater earthquake of above 7.0 in magnitude. The earthquake results in massive waves of hundreds of kilometers per hour traveling into an open ocean (distant tsunami) and moving inland toward the seashore (local tsunami). As the local tsunami waves move closer to the shore, the velocity is decreased to 30 to 40 km/hr [4]. However, the waves compress and build up in height and can be up to 10 m [1]. As a result, tsunami waves appear like a bore or wall of water, scouring away the shoreline and objects in their paths. Due to velocity, height and strength, tsunami waves travel much further inland than a normal wave and can result in significant destruction [4].

The major cause of deaths due to tsunamis is drowning [9]. For victims who survived to receive medical care, the most frequent injuries were trauma due to blunt and crush forces, and aspiration [4,10,11]. Blunt and impaling injuries from floating debris (wood, rock, concrete, metal), and crush injuries due to compression of victims body parts by large masses (trees, houses, motor vehicles) is common [6]. Musculoskeletal injuries are the most prevalent injuries of tsunami patients. In addition to acute trauma, victims frequently aspirate tsunami water [11].

Traumatic Wounds and Wound Infections

Wounds caused by tsunami trauma are typically contaminated by seawater, soil and particulate matters [12–14]. Even small, minor wounds and abrasions could lead to rapid, overwhelming infection. Characteristic lacerated wounds in tsunami patients have a small opening with a large internal pocket that may contain foreign bodies including sand, wood, or debris [15]. Retained foreign bodies may easily be overlooked during an initial wound cleansing, and patients may develop soft tissue infection, sepsis, or present later with persistent drainage [16]. Wounds are often multiple and located in the extremities. Lower extremity wounds are more prevalent than that of the upper extremities [12,15].

Tsunami wounds are frequently infected with multiple bacterial pathogens, notably *Aeromonas* spp. [16]. Other organisms include *Staphylococcus* spp., *Streptococcus* spp., *Vibrio* spp., *Pseudomonas* spp., and *Burkholderia pseudomallei (B. pseudomallei)* [11,14]. Infections with multi-drug resistant bacteria are not unusual, especially among hospitalized patients with long-standing wound infection [4,13,17]. Rare, progressive mucormycosis of the soft tissue has been reported [18]. In a small subset of patients, delayed-onset wound infection with mycobacteria (i.e. *Mycobacterium abscessus*, *Mycobacterium fortuitum*) may appear in the skin near primary sutured wounds or skin grafts up to 3–4 months after the tsunami [15]. A late complication of tsunami wounds includes tetanus [11].

Although an imaging evaluation typically has a limited role in the diagnosis of wounds and wound infections; ultrasound, computed tomography (CT) and magnetic resonance (MR) imaging can provide useful diagnostic information in addition to

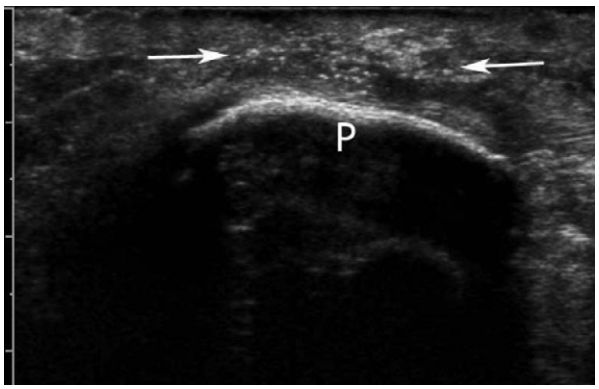

Fig. 1. *Sand in soft tissue of the knee. A transverse ultrasound image of the knee, anterior to the patella (P), shows multiple hyperechoic dots (arrows) in the soft tissue of the prepatellar region.*

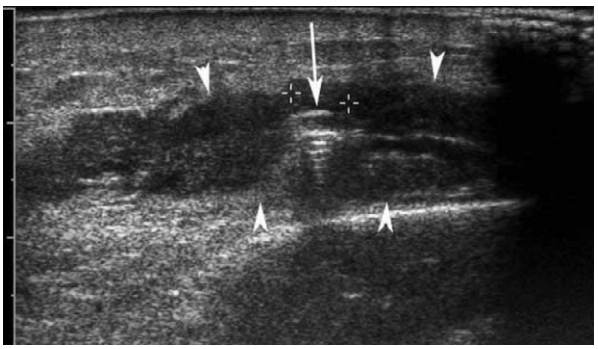

Fig. 3. *Soft tissue abscess in the lower leg. A longitudinal ultrasound image shows a defined area of hypoechogenicity (arrowheads), containing gas (arrows). Note the reverberation artifact beneath gas.*

Fig. 2. *Sand in the soft tissue of the first metatarsal web. A conventional radiograph shows several dots of semi-opaque foreign bodies (arrows) in the soft tissue of the first metatarsal web.*

clinical examinations. Soft tissue injuries (edema, avulsion, laceration, foreign bodies) are the most common musculoskeletal findings, four times more frequent than skeletal trauma. Retained foreign bodies were visualized on radiography and/or ultrasound in 16% of patients with soft tissue injuries [8]. Ultrasound has been utilized to detect foreign bodies in the soft tissues [19], including in tsunami patients (Figs. 1–3) [8]. Sand in the wound may appear as hyperechoic dots. A piece of wood retained in the soft tissue may be suggested on radiography and can be readily detected with ultrasound. It may appear as an oblong hyperechoic region (wood) with surrounding a hypoechoic rim (inflammatory tissue). Ultrasound of the soft tissues also can show abscess, seroma, hematoma, and sinus tracts due to tsunami trauma [8]. CT and MRI can show the extent and severity of soft tissue infection, or if any, evidence of osteomyelitis. Findings on CT or MRI may be used to differentiate necrotizing fasciitis from cellulitis in these patients [20].

Extremity Fractures and Dislocations

Extremity fractures and dislocations are common among tsunami patients with lower extremity predominance accounting for approximately 7% to 15% of tsunami injuries [8,12]. They can present as either open or closed fractures [5]. Open fractures are often severely contaminated, similar to other tsunami wounds.

Fractures and dislocations of the extremities are often apparent on conventional radiography (Fig. 4). CT may be performed when there is a suspicion of occult fracture, to determine the extent of a known fracture, and to assess fractures in regions that may be obscured on radiographs such as the wrist, elbow, pelvis, hip, knee and foot. MRI is a preferred method to evaluate ligamentous injuries that may occur in tsunami patients (Fig. 5) [8,21].

Fig. 4. *Ankle fracture. An anteroposterior radiograph of the left ankle reveals a transverse fracture of the medial malleolus and an oblique fracture of the distal fibula at the level above the tibial plafond. Findings are consistent with pronation-abduction injury.*

Thoracic, Abdominal and Pelvic Trauma

Thoracic, abdominal and pelvic trauma is not frequent. It is possible that victims with severe thoracoabdominal injuries may not have survived the event [10]. When present, both blunt and penetrating trauma have been described. Pneumothorax, hemothorax and rib fractures are among the most common traumatic manifestations in the thorax [8,14]. For abdominal and pelvic trauma, injuries to the abdominal wall, pelvic fracture, testicular injury and liver laceration have been reported [8].

While most thoracic trauma may be readily apparent on chest radiography, CT can provide an accurate diagnosis and define an extent of trauma which may be superior to radiography. CT can be used to differentiate pulmonary contusion and aspiration, detect occult pneumothorax, diagnose hemothorax and other significant thoracic injuries [22]. In the cases of abdominal trauma, CT is able to depict solid organ injuries, hemoperitoneum and pneumoperitoneum due to trauma with high accuracy [23].

Fig. 5. *Tear of medial collateral ligament of the knee and bone contusion of lateral tibial plateau. Coronal proton density magnetic resonance image (MRI) with fat suppression of the left knee demonstrates a tear of the medial collateral ligament (arrow), adjacent soft tissue edema, joint effusion, and a bone contusion of the lateral tibial plateau (arrowheads).*

Head, Facial and Spinal Trauma

Intracranial trauma is rarely reported in tsunami patients. Like trauma to the thoracic and abdominal organs, patients may not have survived the incident to reach the hospital [10]. Facial and spinal fractures in tsunami patients have been reported [8].

Injuries to the face and spine in tsunami patients are usually due to blunt force. Fractures of the face may involve any bones including the frontal, sphenoid, zygoma, maxilla, mandible and nasal bones. Spinal injuries may occur with or without neurological deficits. CT is superior to radiography in the assessment of facial fractures [24]. MRI has an important role in the detection of spinal cord injury.

Aspiration Pneumonia

Aspiration of seawater, mud, and marine debris into the respiratory tract provides pathogenic inoculum of pulmonary infection, inducing pneumonitis

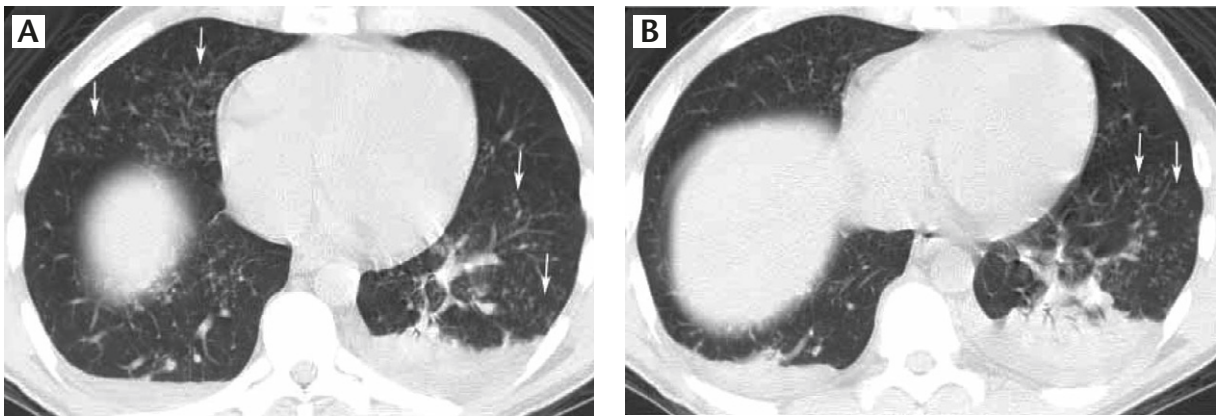

Fig. 6. *Tsunami-related aspiration pneumonia. Axial computed tomography (CT) images (A, B) show tree-in-bud opacities (arrows) in the right middle, right lower and left lower lobes. Bilateral pleural effusions are present. Consolidation in the left lower lobe is also seen adjacent to an effusion.*

and pneumonia. Aspiration is common among tsunami patients. In a published article of 2,311 tsunami patients, 40% reported aspiration during the event. Two percent developed pulmonary complications associated with near drowning [12]. Tsunami patients not only aspirate water, but also soil and particulate matters. Therefore, they are at high risk of polymicrobial infection of the lungs with various pathogens including *Aeromonas* spp., *Pseudomonas* spp. Pneumonias due to unusual pathogens (such as *B. pseudomallei*) have been reported. In tsunami-related melioidosis, patients usually present with a higher frequency of shock, respiratory failure, renal failure and mortality when compared to non-tsunami melioidosis [25]. 'Tsunami lung' or 'tsunami-related aspiration pneumonia' is used to describe lung pathology in tsunami patients who have necrotizing, cavitary pneumonia that may be complicated with empyema, pneumothorax and hematogenous spread of infection [11,26]. Cavitary pneumonia usually develops approximately 1 month after the event [26]. It is usually not responsive to several broad-spectrum antibiotics. Aspiration pneumonia related to near drowning is an important cause of death among tsunami patients [10].

Acute massive aspiration produces a pattern of non-cardiogenic pulmonary edema. Classic radiograph findings include bilateral, diffuse airspace pulmonary opacities radiating from the hila. In milder cases, there are confluent irregular perihilar opacities or tree-in-bud opacities (Fig. 6). When pneumonia develops, areas of confluent airspace disease along the bronchovascular regions, or confined to the lobar distribution of the lung, are seen [8,27]. Findings of necrotizing bronchopneumonia that can be seen include cavity, pneumothorax and/or empyema (Fig. 7) [11]. Clinical and radiological evidence of pneumonia is usually evident at the time of diagnosis [14].

Tsunami Sinusitis

Paranasal sinusitis in tsunami patients is not uncommon. It was found in nearly 10% of all tsunami patients in one series [8]. In another series of patients in an ICU setting, Maegele et al found three of 17 tsunami victims with severe sinusitis. *Tsunami sinusitis* refers to polymicrobial infection of paranasal sinuses in tsunami patients whose sinuses often contain sand materials [14]. It was originally described in a nearly-drowned tsunami victim with CT findings of fluid and opaque materials in the ethmoid, maxillary and sphenoid sinuses, which were proven to be sand and purulent materials [21]. Retained sand within the sinuses may be a sequalae of inhaled seawater and mud during a near drowning episode. Seawater and sand may enter the sinuses through sinus ostia and therefore remains

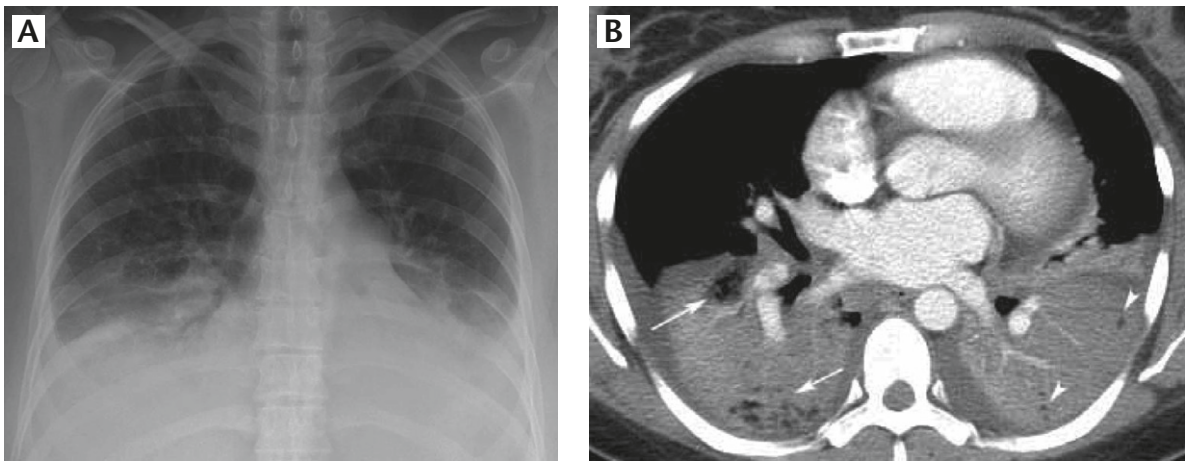

Fig. 7. *Tsunami-related aspiration pneumonia with cavity formation. Chest radiograph (A) shows bilateral lower lobe opacities with pleural effusions. Axial computed tomography (CT) image (B) reveals bilateral lower lobe consolidations with scattered ill-defined areas of low attenuations (arrows), representing small cavities.*

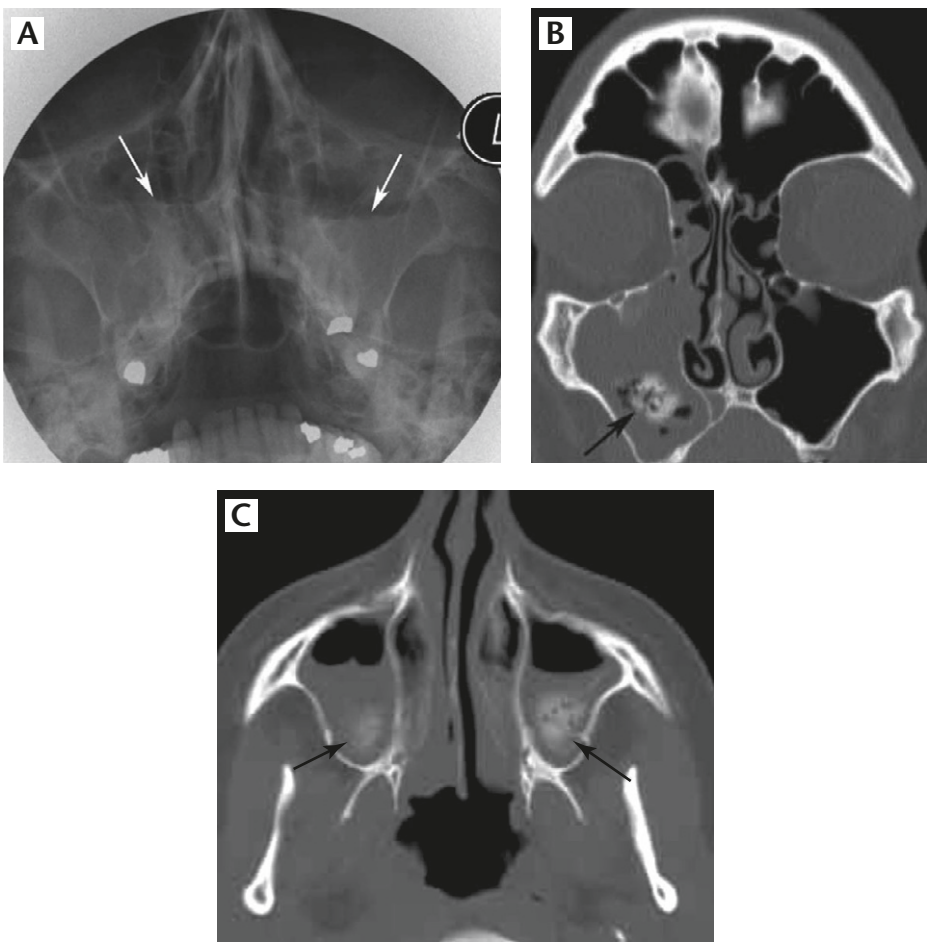

Fig. 8. *Tsunami sinusitis. A paranasal sinus radiograph (A) shows haziness of bilateral maxillary sinuses with air-fluid levels (white arrows). The patient was treated for sinusitis with antibiotics but presented with persistent sinus symptoms. Coronal computed tomography (CT) image (B) obtained 1 month after the radiograph shows a persistent right maxillary sinusitis with high attenuation materials within (black arrow). Axial CT image of another patient (C) shows air-fluid levels in bilateral maxillary sinuses that contain high attenuation materials (black arrows). Antral lavages revealed purulent materials and sand in the sinuses.*

within the sinuses of tsunami victims. Secondary infection with multiple organisms follows.

Findings of sinusitis is seen on conventional radiography as haziness and mucoperiosteal thickening of the affected sinuses. These are readily confirmed on CT. On CT, air-fluid levels are commonly present. In the majority of cases, high attenuation materials are seen at the most dependent portion of the sinuses, which may represent retained sand (Fig. 8) [8]. The presence of high attenuation materials in the sinuses of tsunami victims should alert radiologists to suggest a possibility of retained sand in the sinuses and coexisting polymicrobial infection.

In conclusion, there is a wide range of injuries and diseases in patients suffering from tsunami trauma. Two of the most common entities are extremity trauma and aspiration of sea water. Radiologic examinations help detect and follow up these abnormalities. They may provide crucial information of certain conditions obscured in clinical examinations such as retained soft tissue foreign bodies and tsunami sinusitis.

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